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Evaluation of the Compressed Air Foam System-Mobile (CAFS-M)

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Notices

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

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The Marine Corps has approved the replacement of the Twin Agent Unit (TAU) with the Compressed Air Foam System-Mobile (CAFS-M) to provide initial response fire protection capabilities. Modifications were performed on the CAFS-M due to issues on the adequacy of the system to meet mission requirements. This test series validated the modifications, reconfirmed the CAFS-M capabilities and determined the radiant heat effects on firefighters while using the system. A series of seven JP-8 pool fires, ranging in size from 2500 to 7800-ft^2, were used to evaluate the 90% control and full extinguishment times. The effects of radiant heat on the firefighter were monitored using a remote telemetry data acquisition system to monitor skin temperature using temperature probes. System operation was evaluated by conducting tests for throw distance, agent duration, agent stream decay, agent flow rate, expansion ratio, 25% drainage time and foam concentration. The CAFS-M controlled and extinguished all fires within the maximum time criteria. The CAFS-M is capable of extinguishing fires twice the minimum requirement using only 25% of its capacity. Skin temperature measurements confirmed that the CAFS-M provided adequate performance to reduce radiant heat exposure and prevent any subsequent burns. System evaluation showed no performance inadequacies.

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Abstract

The Marine Corps has approved the replacement of the Twin Agent Unit (TAU) with the Compressed Air Foam System-Mobile (CAFS-M) to provide initial response fire protection capabilities. Modifications were performed on the CAFS-M due to issues on the adequacy of the system to meet mission requirements. This test series validated the modifications, reconfirmed the CAFS-M capabilities and determined the radiant heat effects on firefighters while using the system. A series of seven JP-8 pool fires, ranging in size from 2500 to 7800-ft^2, were used to evaluate the 90% control and full extinguishment times. The effects of radiant heat on the firefighter were monitored using a remote telemetry data acquisition system to monitor skin temperature using temperature probes. System operation was evaluated by conducting tests for throw distance, agent duration, agent stream decay, agent flow rate, expansion ratio, 25% drainage time and foam concentration. The CAFS-M controlled and extinguished all fires within the maximum time criteria. The CAFS-M is capable of extinguishing fires twice the minimum requirement using only 25% of its capacity. Skin temperature measurements confirmed that the CAFS-M provided adequate performance to reduce radiant heat exposure and prevent any subsequent burns. System evaluation showed no performance inadequacies.

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Executive Summary

I. Introduction

A. *Background*

The Assistant Commandant of the Marine Corps approved the Operational Requirements Document (ORD) for the Compressed Air Foam (CAFS) Mobile (hereafter referred to as the CAFS-M) to replace the M1028FF Twin Agent Unit (TAU). The CAFS-M replacement must provide initial response fire protection capabilities to the Marine Air Ground Task Force Air Combat Element and Combat Service Support Element.

Previous testing completed on the CAFS-M have raised some issues as to the adequacy of the system to meet mission requirements. Testing revealed that optimization of the system should improve performance and expand capabilities similar to that of the TAU.

B. *Purpose*

Testing conducted at China Lake, CA in November 2000 indicated that the CAFS-Ms passed the requirements stated in the ORD. A series of modifications have been completed and a new nozzle has been proposed for use with the system. These tests will validate the modifications, reconfirm the CAFS-M capabilities and determine the effect of firefighting on human factors during various size fires.

C. *Scope*

The CAFS-M was tested to evaluated the following:

- Firefighting capability including: (using system M2501810)
    - 90% extinguishment time of a 2500-ft^2 JP-8 pool fire
    - Extinguishment time of a 3500-ft^2 JP-8 pool fire
    - Extinguishment time of a 7800-ft^2 JP-8 pool fire

- Human Factors including:
    - Radiant heat effects on firefighters

- System parameters including: (using systems M2501810 and M2501800)
    - Maximum throw distance at 0° (level) and maximum
    - Agent application duration
    - Agent stream decay over application time
    - Agent flow rate
    - Foam agent concentration
    - Foam expansion ratio
    - Foam drainage time, 25%

II. Results and Conclusions

A. *Fire Scenarios*

All four 2500-ft^2 fires were controlled within the ARFF required time of 60 seconds, with the exception of test 2500-1 (practice test). Full extinguishment times ranged between 55.97-62.93 seconds, exceeding ARFF requirements by almost a full minute. The 3500 and 7800-ft^2 fires showed similar control and extinguishment times ranging from 63.54-66.75 seconds for 90% control and 75.49-80.51 seconds for full extinguishment.

1. 2500 Sq. Ft. Fires

The CAFS-M exceeded the ARFF requirements for control (<60 seconds) and extinguishment (<120 seconds) of a 2500-ft^2 hydrocarbon pool fire. All four fires reported control time less than 60 seconds and extinguishment times less than 63 seconds.

2. 3500 Sq. Ft. Fire

The CAFS-M demonstrated improved fire control and extinguishment times of a 3500-ft^2 hydrocarbon pool fire. While maximum control and extinguishment times were not established for this test, the CAFS-M was able to fully extinguish the pool fire within the 120 second criteria established for the 2500-ft^2 pool fires. Modifications to the CAFS-M, especially the increase in agent flow rate, have drastically improved the performance of the system in both control and extinguishment times.

3. 7800 Sq. Ft. Fire

The 7800-ft^2 test was performed with winds of 4-5 mph. Due to the increase in wind velocity, the fire only involved approximately 2/3, or 5200-ft^2, of the 7800-ft^2 full pit area. While maximum control and extinguishment times were not established for this test, the CAFS-M was able to fully extinguish the pool fire within the 120 second criteria established for the 2500-ft^2 pool fires. The CAFS-M successfully controlled and extinguished a 5200-ft^2 hydrocarbon pool fire without depleting the system capacity. Based on the time to full extinguishment, the CAFS-M used approximately 25% of its available agent while extinguishing more than two times the required pool fire area.

B. *Radiant Heat Effects on Firefighters*

Generally, results indicated that skin temperature remained below 102°F at all four probe locations. Hand temperature readings (99-100°F) exceeded thigh temperature readings during test 2500-1 and 2500-2. However, the trend in the data showed higher temperatures at the thigh (97-101°F), closely followed by the hand (98-100°F). Neck temperatures, while expected to exceed the three other

readings, remained low during all seven tests. In every test, except 2500-3 and 3500-1, the neck probe indicated the lowest skin temperature reading.

Skin temperature measurements were consistent at 102°F or less. The throw distance and discharge rate of the CAFS-M allowed the firefighter to maintain a safe standoff distance from the fire, which reduced radiant heat exposure and prevented any subsequent skin burns.

C. *System Evaluation*

1. Throw distance

All three tests showed a maximum throw range (with or without wind) of 64-73 feet, or well beyond the 50-foot minimum distance criteria.

Both systems exceeded minimum requirements of a 50-foot throw distance in straight stream mode by 14-23 feet. The CAF-M has sufficient throw distance to provide adequate standoff distance for the firefighter, minimizing radiant heat exposure.

2. Application duration

Both systems showed consistent application duration times in excess of five minutes and within a nine second tolerance of each other.

The CAFS-M has sufficient agent application to completely extinguish a fire three times the minimal requirement using only 25% of its capability.

3. Agent stream decay over application time

Evaluation of the video from both systems showed that the agent stream remained steady in flow rate and throw distance until the water level became to low for the pump to siphon. This data showed that the firefighter could expect over 4½ minutes of consistent agent application.

The CAFS-M provided consistent agent throw during the entire system capacity. The agent stream did not decrease in throw range until the water level in the tank became to low for the pump to siphon.

4. Agent flow rate

The flow rates were similar between tests/vehicles and ranged from 37.37-38.44 gpm. NFPA 414 for ARFF vehicle flow rate tolerances states that the flow rate must be +10 percent/-0 percent (35.0-38.5 gpm) of the manufacturers specifications. Based on a 35 gpm manufacturer specification, the CAFS-M flow rate was within NFPA standards.

5. Foam agent concentration

Refractometer method: A Reichert Model 10440, 0-30 Hand Refractometer was used for taking readings. Refractometer readings showed a consistent 3% foam concentration.

Agent use method: Foam concentrations calculated on the quantities of water and foam used for each test showed that the foam concentration was consistently over the desired 3%. Foam concentrations ranged from 3.5-4.24% during the six fire scenario tests evaluated.

Both methods employed for determining foam concentration showed that the CAFS-M maintained a minimum of 3% foam concentration.

6. Foam expansion ratio and 25% foam drainage time

Foam expansion ratio and drainage tests conducted on the foam produced from test M2501810-2 showed that the system exceeded minimum requirements as stated in NFPA 412. NFPA minimum requirements for aspirated (or compressed air) AFFF are 5:1 expansion ratio. System M2501810 produced foam with an expansion ratio of 5.73-5.85:1. Similarly, the NFPA minimal requirement for 25% drainage time using test method A is 3 minutes. System M2501810 produced foam with a 25% drainage time of 4.27-4.36 minutes.

The CAFS-M (on the wet setting) exceeded minimum NFPA 412 requirements for foam expansion ratio and 25% drainage times.

I. Introduction

A. *Background*

The Assistant Commandant of the Marine Corps approved the Operational Requirements Document (ORD) for the Compressed Air Foam (CAFS) Mobile (hereafter referred to as the CAFS-M) to replace the M1028FF Twin Agent Unit (TAU).[1] The TAU has developed reliability problems in several major subsystems that degrade readiness and its host vehicle (M1008 Commercial Utility Cargo Vehicle (CUCV)) is no longer in the inventory. The CAFS-M replacement must provide initial response fire protection capabilities to the Marine Air Ground Task Force Air Combat Element and Combat Service Support Element. CAFS-M requirement capabilities and key performance parameters (KPP) are outlined in the ORD. One KPP is that the CAFS-M maintain no less than the present firefighting capability of the TAU; however, there is no known existing test data available on the TAU. Furthermore, the TAU uses a twin agent, whereas, the CAFS-M uses a single agent for firefighting.

Previous testing completed on the CAFS-M have raised some issues as to the adequacy of the system to meet mission requirements. Testing revealed that optimization of the system should improve performance and expand capabilities similar to that of the TAU.

B. *Purpose*

Testing conducted at China Lake, CA in November 2000 indicated that the CAFS-Ms passed the requirements stated in the ORD. During the past 18 months, numerous tests have been conducted, indicating that the CAFS-M has passed the requirements stated in the ORD. A series of modifications have been completed and a new nozzle has been proposed for use with the system. These tests will validate the modifications, reconfirm the CAFS-M capabilities and determine the effect of firefighting on human factors during various size fires.

C. *Scope*

The CAFS-M was tested to evaluated the following:[2]

- Firefighting capability including: (using systems M2501810)
  - 90% extinguishment time of a 2500-ft^2 JP-8 pool fire
  - Extinguishment time of a 3500-ft^2 JP-8 pool fire
  - Extinguishment time of a 7800-ft^2 JP-8 pool fire

- Human Factors including:
  - Radiant heat effects on firefighters

- System parameters including: (using systems M2501810 and M2501800)
  - Maximum throw distance at 0° (level) and maximum

- Agent application duration
- Agent stream decay over application time
- Agent flow rate
- Foam agent concentration
- Foam expansion ratio
- Foam drainage time, 25%

II. Methods, Assumptions and Procedures

A. *Test Vehicles*

MARCORSYSCOM delivered two test vehicles to Tyndall AFB, FL for the duration of testing. Examination of the vehicles/CAFS-Ms by MARCORSYSCOM technicians determined both vehicles to be in proper working order at the time of arrival. Assuming no mechanical problems during testing, AFRL and MARCORSYSCOM agreed that use of a single CAFS-M system would eliminate the variable of differences in system performance because of slight variations between the two systems. During all fire scenarios, system number M2501810 was used for all firefighting. Both CAFS-Ms were used for system evaluation to determine any differences between systems (i.e. throw distance, agent application duration, agent concentration, etc). The second system used during system evaluations was numbered M2501800.

B. *Firefighter Qualifications*

All AFRL Fire Research firefighters are retired Air Force firefighters, with a minimum of 25 years of experience. All professional training in aircraft rescue and firefighting was received from the Air Force.

C. *Fire Scenarios*

1. 2500 Sq. Ft. Fires

a. Description

A 56.4 ft diameter ring was constructed in the center of the Large Scale Fire Evaluation Facility (Fire Pit) using 6" X 8' strips of steel. The steel ring was covered in a layer of course aggregate to dissipate the heat from the fire and protect the ring from warping. The Fire Pit was filled with 750 gallons of JP-8 jet fuel (approximately 0.3 gal/ft^2) on top of a 3-inch layer of water. The CAFS-M was fully serviced prior to each fire and discharged for approximately 30 seconds prior to lighting the fire as a pre-fire system check. A propane torch was used to ignite the JP-8 and a pre-burn of 60-75 seconds was conducted to assure full involvement of the fuel in the fire area. The firefighter was given a ten second countdown, at which time a steady attack mode was used to extinguish the fire. A steady attack mode is characterized by moderate speed sweeps of the nozzle. This type of attack is more effective than a quick, aggressive attack mode for fuel on water pool fire for two reasons:

- Pushes a layer of foam over the fuel fire, assuring complete foam blanket coverage.
- Assures the foam stream (especially when using a straight stream nozzle pattern) does not disturb the pool surface, causing the fire to flash back.

Time to extinguishment was based on extinguishment of the fire on the pool of water. Fire remaining on the aggregate protecting the ring was not considered part of the square footage of the fire or extinguishment time.

b. Criteria for Success

The series of 2500 ft^2 fires were used to determine the control and extinguishment times of a Class B Pool Fire, which represents the practical critical area for the V-22.[3] Based on Aircraft Rescue and Firefighting (ARFF) maximum allowable standards, the test was considered a success if the fire was controlled within 60 seconds and extinguished within 120 seconds. Control time is defined as the time required to extinguish 90% of the fire area whereas extinguishment time is defined as the timer required to extinguish 100% of the fire area.

2. 3500 Sq. Ft. Fire

a. Description

The 56.4 ft diameter ring was expanded to 66.8 ft to accommodate the 3500-ft^2 fire. Only one fire of this size was extinguished, therefore, the aggregate was not needed for protection and was moved to the outer edges of the Fire Pit. The Fire Pit was filled with 1050 gallons of JP-8 jet fuel (approximately 0.3 gal/ft^2) on top of a 3-inch layer of water. The CAFS-M was fully serviced prior to each fire and discharged for approximately 30 seconds prior to lighting the fire. A propane torch was used to ignite the JP-8 and a pre-burn of 60-75 seconds was conducted to assure full involvement of the fuel in the fire area. The firefighter was given a ten second countdown, at which time a steady attack mode was used to extinguish the fire. Time to extinguishment was based on extinguishment of the fire on the pool of water. Any fire extinguished outside the ring was not included in the final time.

b. Criteria for Success

This test series did not correlate to any existing NFPA requirements; therefore, no maximum control or extinguishment times were established. The test was conducted to provide MARCORSYSCOM with an estimation of current system performance for comparison with previous test data.

3. 7800 Sq. Ft. Fire

a. Description

After successful extinguishment of the 2500-ft^2 and 3500-ft^2 fires, a 7800-ft^2 full pit fire was prepared. The steel ring from the previous fire was removed so that the full 100-ft diameter pit area could be utilized. An additional 1500 gallons of JP-8 jet fuel was added to the Fire Pit to assure as complete a fire coverage area as possible, given the wind conditions (5-6 mph winds were pushing the fuel to the west side of the pit). A longer pre-burn time was necessary to assure full involvement of the fuel in the fire area. The firefighter extinguished the fire using

the same attack techniques as in the two previous size fires. Time to extinguishment was based on the extinguishment of the fire on the pool of water. Any fire extinguished on the banks of the Fire Pit area was not included in the final time.

b. Criteria for Success

This test series did not correlate to any existing NFPA requirements; therefore, no maximum control or extinguishment times were established. The test was conducted to take the CAFS-M to failure by subjecting the system to a fire three times the size of the minimum requirements.

D. *Human Factor Evaluation*

1. Radiant Heat Effects on Firefighters

Concern about radiant heat exposure during previous CAFS-M testing has prompted skin temperature monitoring of the primary firefighter during each fire scenario. Continuous monitoring will assure temperatures severe enough to cause burns are not being approached. Information available from the American Burn Association relates exposure time and temperature to third degrees burns (Figure 1).[4] The time to sustain a third degree burn decreases exponentially once the temperatures exceeds 120°F.

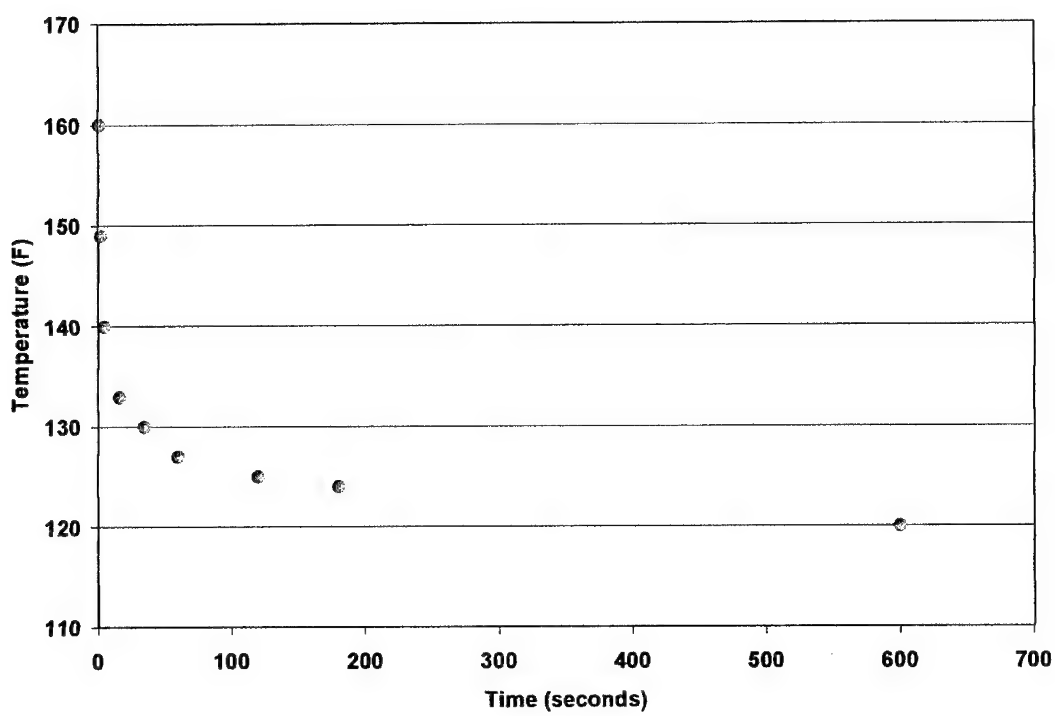

Figure 1. Estimated Times vs. Temperatures Causing a Third Degree Burn

Prior testing of NFPA standard proximity gear (coat, trouser, helmet/shroud and gloves) by AFRL showed that the neck area was most prone to elevated

temperature readings. The shroud (attached to the helmet) generally does not provide the same level of protection as the rest of the proximity suit because it is not constructed with the same thickness as the coat and trousers.

Skin temperature was monitored using the Mini Mitter VitalSense Telemetric Monitoring System on the primary firefighter during all fires. The same firefighter was used for all seven fires to eliminate any variations in skin temperature measurements due to differences in individual body temperature. Four temperature probes were placed in direct contact with the skin at the following locations:

- Neck
- Chest
- Upper front thigh
- Back of hand

The probes were connected to the VitalSense remote monitor system that transmitted the measurements to the local monitor, connected to a Dell Inspiron 3800 Pentium III 600 notebook computer. The data acquisition rate was approximately one sample per three seconds.

2. Criteria for Success

This test series did correlate to any NFPA requirement; therefore, known skin burn data was used as the comparison. Skin temperatures experienced for the duration of firefighting less than 120°F were considered an acceptable level.

E. *System Evaluation*

Each of the two CAFS-M systems was fully serviced prior to agent discharge. Maximum throw distance, agent application duration, agent stream decay and agent discharge flow rate were performed for informational purposes only (as no minimum guidelines or standards were established prior to testing). Only discrepancies observed or measured during testing will be explained in the conclusions section of the report. The last three tests (expansion ratio, drainage time and foam concentration) produced data that can be compared to established minimum standards.

1. Maximum Throw Distance

Throw distance and discharge rate are two important factors in the standoff distance a firefighter can maintain during firefighting, which, in turn, determines radiant heat exposure.

The firefighter was situated around the Fire Pit such that the agent would be discharged in the prevailing direction of the wind.

O° (level)

The firefighter held the nozzle at waist height, parallel to the ground while the agents were discharged. A cone was used to mark the maximum throw distance at this angle.

Maximum without wind

After the maximum throw distance at O° was determined, the firefighter slowly raised the nozzle to the angle that would maximize the throw distance (approximately 20°). A separate cone was used to mark the maximum throw distance at this angle.

Maximum with wind

During evaluation of the maximum throw distance, short gusts of wind (5-6 mph) extended the throw distance beyond that measured without wind. A separate cone was used to mark the maximum throw distance with wind gusts.

At the completion of the agent discharge, a tape measure was used to determine the exact throw distance for each elevation.

Criteria for Success

This test series did not correlate to any NFPA requirement. However, a Marine ORD requirement required a continuous foam spray of 20 feet (threshold) and a straight foam stream of 50 feet (threshold). Evaluation of throw distance only included the nozzle in a straight stream mode.

2. Agent Application Duration

Agent application duration was measured by timing the agent discharging starting with a full foam and water tank and discharging until empty. The water tank was the first to empty because the foam tank (11 gallons) capacity is greater than the water tank (200 gallons) when the foam is used at a 3% concentration.

Criteria for Success

This test series did not correlate to any NFPA requirement. The 7800-ft^2 fire was performed to evaluate the CAFS-M on a fire with over three times the minimal pool fire extinguishment area. Success was defined by complete extinguishment of the total fire area without depleting the system agent capacity.

3. Agent Stream Decay over Application Time

Agent decay was evaluated by reviewing video of the agent discharge testing. Agent discharge decay is defined as the point at which the agent stream begins to lose throw distance.

Criteria for Success

This test series did not correlate to any NFPA requirement and results are given for informational purposes only.

4. Agent Discharge Flow Rate

The agent discharge flow rate was determined by dividing the total amount of agent discharged by the time the agent took to discharge.

Criteria for Success

NFPA 414 requires the measured flow rate to equal the specified flow rate within a tolerance of +10 percent/-0 percent.[5] The specified flow rate of the CAFS-M was nominally 30 to 35 gpm on full wet setting.

5. Foam Expansion Ratio

Foam expansion ratio was measured by the methods specified in the National Fire Protection Agency (NFPA) 412, Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment (See Appendix for complete description of method).

Criteria for Success

NFPA 412 requires a minimum expansion ratio of 5:1 for air-aspirated AFFF.[6]

6. Foam Drainage Time, 25%

Foam drainage time, 25% was measured by the methods specified in the National Fire Protection Agency (NFPA) 412, Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment (See Appendix for complete description of method).

Criteria for Success

NFPA 412 requires a minimum 25% foam drainage of three minutes for air-aspirated AFFF using Test Method A.

7. Foam Concentration

Two methods were used during testing to determine agent concentration.

By Refractometer

Foam agent concentration was measured by the methods specified in the National Fire Protection Agency (NFPA) 412, Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment (See Appendix for complete description of method).

By Quantity of Agent Used

The CAFS-M unit was fully reserviced after each test. During reservicing, the amount of water and foam used to refill the tanks was measured. The foam

concentration was calculated by dividing the amount of foam used by the amount of water used.

Criteria for Success

According to NPFA 412 Standard for Evaluating Aircraft Rescue and Firefighting Equipment, nominal 3% concentrates should range between 2.8 and 4.0 %.

III. Results and Discussion

A. *Fire Scenarios*

Seven fires of three different sizes were conducted over a three-day period. Weather conditions remained constant during the three-day test interval with temperatures in the low 90's and winds generally ranging from 1-4 mph, not exceeding 6 mph.

Time Data Sources

Extinguishment times were collected from four different sources:

- During each fire: Multiple stopwatches were used during each event. Representatives from China Lake, HQMC, MARCORSYSCOM and AFRL Test Director provided time inputs.
- From digital video.
- From camera 1.
- From camera 2.

Differences in 90% control times and full extinguishment times can be attributed to position relative to the fire and individual ability to estimate when the fire has actually been extinguished (especially for the 90% control times). An average of all time sources will be considered the official times for both 90% and full extinguishment.

1. 2500 Sq. Ft. Fires

2500-1

The first 2500-ft^2 fire was used as a practice test to assure the equipment was operating correctly and familiarize the firefighters with the system. Approximately 18 seconds into testing, the agent stream began to decay. A system check concluded that the foam control was not set on "wet" but rather on "20:1". Adjustment of the foam control restored agent flow and the remaining fire was extinguished. The 90% control and full extinguishment times (excluding the time to adjust the foam control) were 61.41 and 66.65 seconds, respectively (Table 1). Because a break in the extinguishment of the fire was experienced, the data from this test are reported for informational purposes only and are not considered as an official test.

Table 1. Extinguishment Times (seconds) and Parameters for Test 2500-1.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
2500-1		During Fire	60.00		101.41
					72.00
Fuel Load	Southeast	From Digital Video		54.28	65.68
750	East	From Camera 1	64.19	66.84	73.88
	North	From Camera 2		63.10	70.30
		Average		**61.41**	**66.65**

2500-2

Test 2500-2 was completed without Incident. While both video cameras were recorded the test, the wind shifted direction, blowing smoke towards camera 2. Therefore, control and extinguishment time data were not obtained from this source for use in the final test average. No problems were encountered with the system and the control time was within ARFF requirements at 46.97 seconds (Table 2), or more than 13 seconds before the 60 second allowance. Full extinguishment was just over one minute at 60.92 seconds.

Table 2. Extinguishment Times (seconds) and Parameters for Test 2500-2.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
2500-2		During Fire	60.00		63.00
					68.00
					59.00
Fuel Load	Southeast	From Digital Video		46.22	54.25
600	Platform	From Camera 1	62.09	47.72	60.34
	North	From Camera 2		No Data	No Data
		Average		**46.97**	**60.92**

2500-3

Test 2500-3 was completed without any incident. No problems were encountered with the system and the control time was within ARFF requirements at 50.98 seconds (Table 3), or more than 9 seconds before the 60 second allowance. In this fire, full extinguishment was also attained prior to one minute at 55.97 seconds.

Table 3. Extinguishment Times (seconds) and Parameters for Test 2500-3.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
2500-3		During Fire	60.00		50.85
					58.50
Fuel Load	Southeast	From Digital Video		47.72	52.56
750	East	From Camera 1	60.63	54.65	62.59
	North	From Camera 2		50.56	55.34
		Average		**50.98**	**55.97**

2500-4

The CAFS-M operated normally during test 2500-4; however, the fire flashed back on the firefighter approximately half way through the test because of a disturbance in the foam blanket caused by the firefighter as he advanced towards the fire. The firefighter was able to quickly put out the fire around his feet and continue to extinguish the remainder of the fire. Since the delay was not caused by equipment problems, the test was considered valid and was included as a data point in the system evaluation. The control time for this fire was under the one-minute requirement at 56.70 seconds with a full extinguishment time slightly over one minute at 62.52 seconds (Table 4).

Table 4. Extinguishment Times (seconds) and Parameters for Test 2500-4.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
2500-4		During Fire	75.00		55.25
					65.94
Fuel Load	Southeast	From Digital Video		52.72	61.44
750	East	From Camera 1	76.50	54.69	64.97
	South	From Camera 2		62.69	65.00
		Average		**56.70**	**62.52**

2500-5

The final 2500 ft^2 fire occurred without incident to the system or personnel. The 90% control time was 50.57 seconds (Table 5), which is consistent with previous tests and meets the criteria for success. Again, the time to full extinguishment was just over one minute at 62.93 seconds.

Table 5. Extinguishment Times (seconds) and Parameters for Test 2500-5.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
2500-5		During Fire	70.00		59.84
Fuel Load	Southeast	From Digital Video		42.47	56.01
750	Southeast	From Camera 1	72.22	62.00	65.29
	South	From Camera 2		47.25	70.59
		Average		**50.57**	**62.93**

2. 3500 Sq. Ft. Fire

One 3500-ft^2 fire was completed during this test series without any incident. The 90% control and full extinguishment time was slightly higher for the 3500-ft^2 versus the 2500-ft^2 fires at 66.75 and 75.49 seconds (Table 6). Previous testing at China Lake with this system demonstrated control and extinguishment times of 102 and 135 seconds (exceeding maximum time allowances). Figure 2 shows the intensity and coverage area of the fire.

Table 6. Extinguishment Times (seconds) and Parameters for Test 3500-1.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
3500-1		During Fire	70.00		75.63
Fuel Load	East	From Camera 1	69.91	69.44	75.35
1050	North	From Camera 2		64.06	75.50
		Average		**66.75**	**75.49**

Figure 2. 3500-ft^2, 1050 Gallon JP-8 Pool Fire.

3. 7800 Sq. Ft. Fire

One 7800-ft^2 fire was completed during this test series without any incident. This test was performed with winds of 4-5 mph. Due to the increase in wind velocity, the fire only involved approximately 2/3, or 5200-ft^2, of the 7800-ft^2 full pit area. The intensity of this fire can be seen in Figure 3. The CAFS-M was able to control and extinguish the fire within the capacity of the system at 63.54 and 80.51 seconds, respectively (Table 7).

Figure 3. 7800-ft^2, 1500$^+$ Gallon Full Pit JP-8 Pool Fire.

Table 7. Extinguishment Times (seconds) and Parameters for Test 7800-1.

			Times (seconds)		
Test Number	**Camera View**	**Test Times Taken**	**Pre-Burn**	**90% Control**	**Full Extinguishment**
7800-1		During Fire	135.00		82.72
Fuel Load	East	From Camera 1	130.69	69.16	77.90
1050	North	From Camera 2		57.91	80.91
		Average		**63.54**	**80.51**

4. Summary

All four 2500-ft^2 fires (Figure 4) were controlled within the ARFF required time of 60 seconds, with the exception of test 2500-1 (practice test). Full extinguishment times ranged between 55.97-62.93 seconds, exceeding ARFF requirements by almost 60 seconds. The 3500 and 7800-ft^2 fires showed similar control and extinguishment times ranging from 63.54-66.75 seconds for 90% control and 75.49-80.51 seconds for full extinguishment.

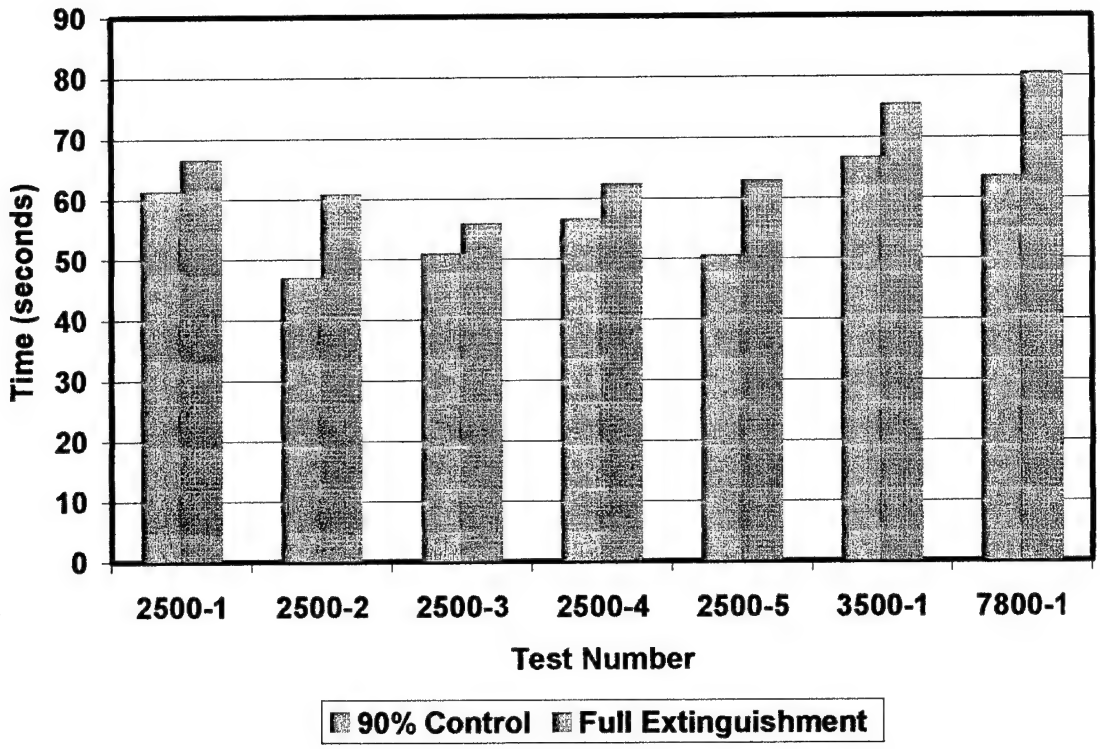

Figure 4. Summary of Control and Extinguishment Times for all Pool Fires.

B. *Human Factors*

Radiant Heat Effects on Firefighters

The data acquisition system was initiated prior to each fire test (hence, the extended time interval prior to the actual fire scenario) to assure the equipment was functioning properly and the data were being collected. The approximate firefighting interval has been circled on each graph to show when the firefighting was actually taking place. Generally, results indicated that skin temperature remained below 102°F (Figures 5-11) at all four probe locations. One anomaly in the test data was the thigh temperature measurement taken during test 2500-5. Temperatures recorded during the actual firefighting interval exceeded 129°F (or a high enough temperature to cause a burn). The manufacturer suggested that this reading was probably an error due to a short in the probe (possibly caused by sweat). The firefighter was questioned about any unusual heat stress experienced during this test. The firefighter stated that the heat intensity experienced was no greater than in other tests where the temperature measurements were under 102°F. With the exception of the single high measurement during test 2500-5, all recorded skin temperature readings were at least 18°F lower than the lowest temperature listed to sustain a third degree burn.

Hand temperature readings (99-100°F) exceeded thigh temperature readings during test 2500-1 and 2500-2 (Figures 5-6). However, the trend in the data showed (Figures 7-11) higher temperatures at the thigh (97-101°F), closely followed by the hand (98-100°F). Neck temperatures, while expected to exceed the three other readings, remained low during all seven tests. In every test, except 2500-3 and 3500-1, the neck probe indicated the lowest skin temperature reading.

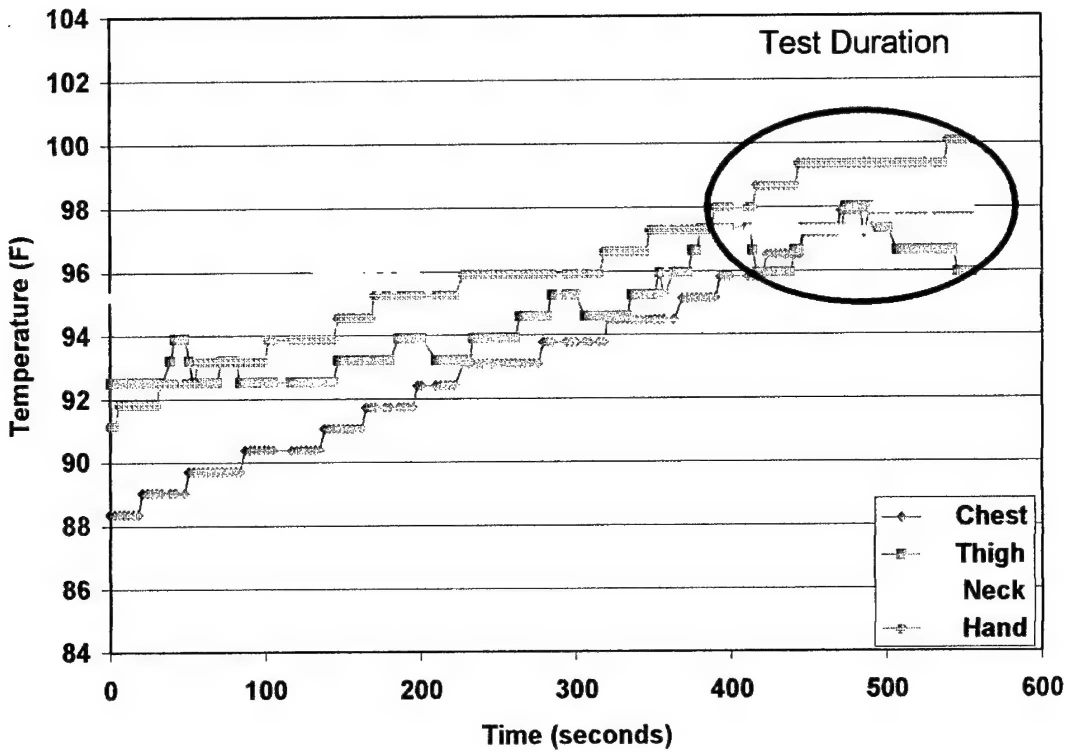

Figure 5. Skin Temperature Measurements for Test 2500-1.

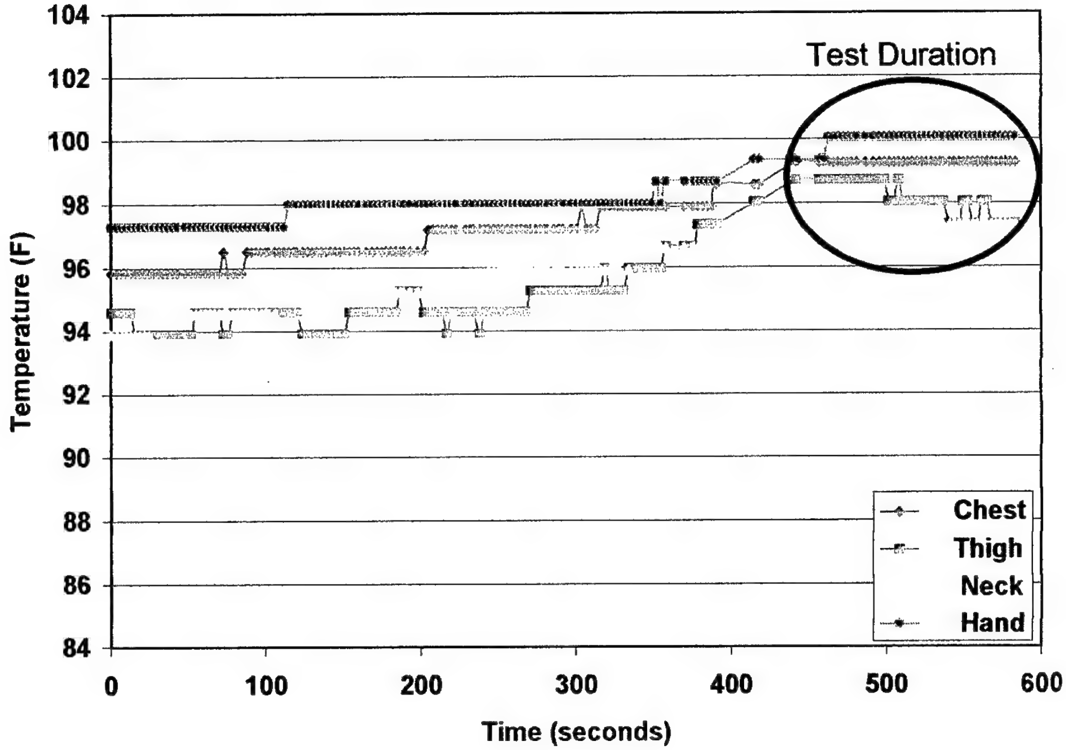

Figure 6. Skin Temperature Measurements for Test 2500-2.

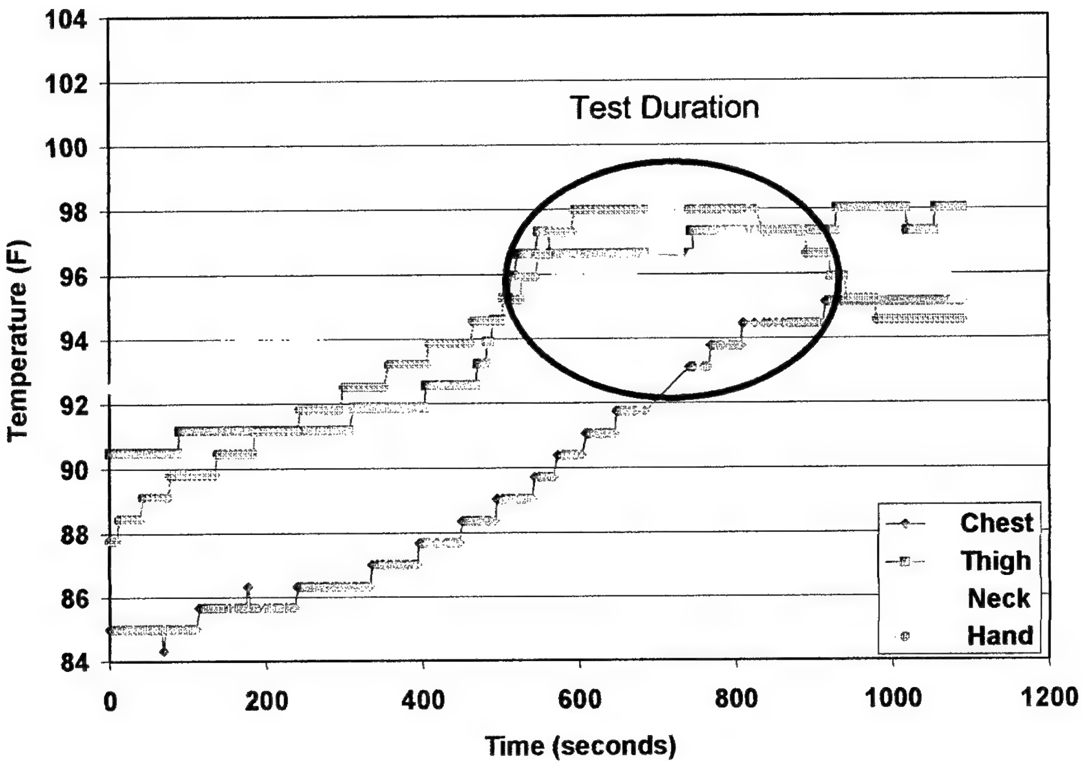

Figure 7. Skin Temperature Measurements for Test 2500-3.

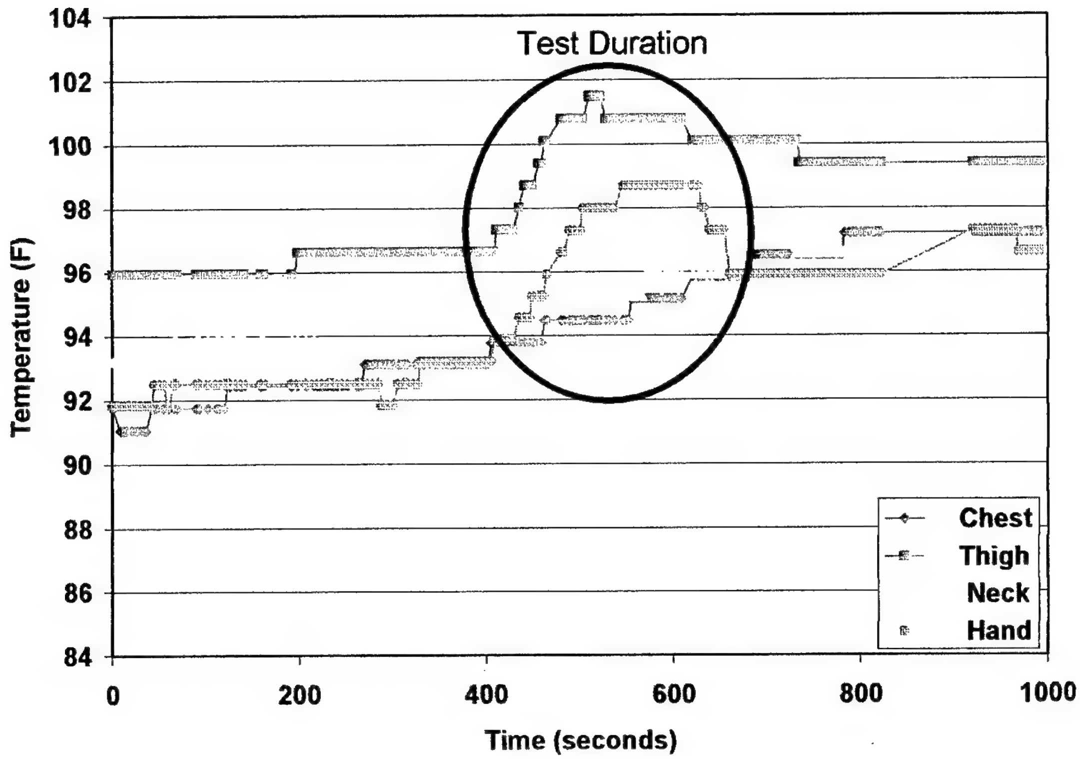

Figure 8. Skin Temperature Measurements for Test 2500-4.

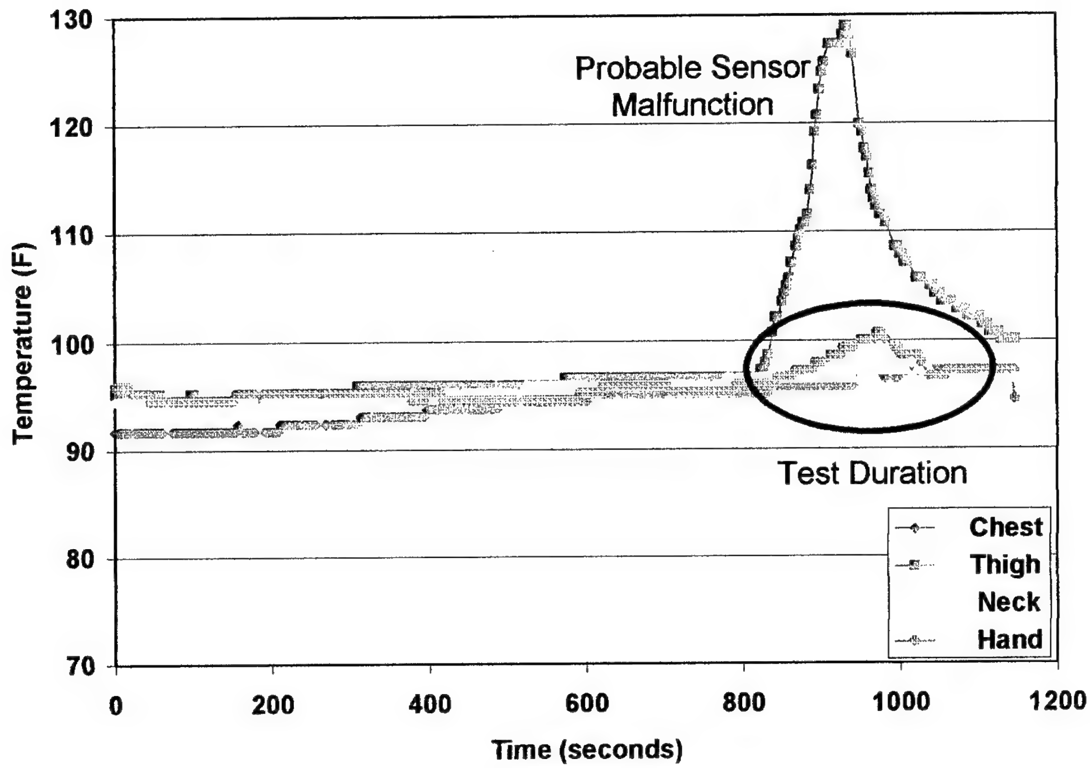

Figure 9. Skin Temperature Measurements for Test 2500-5.

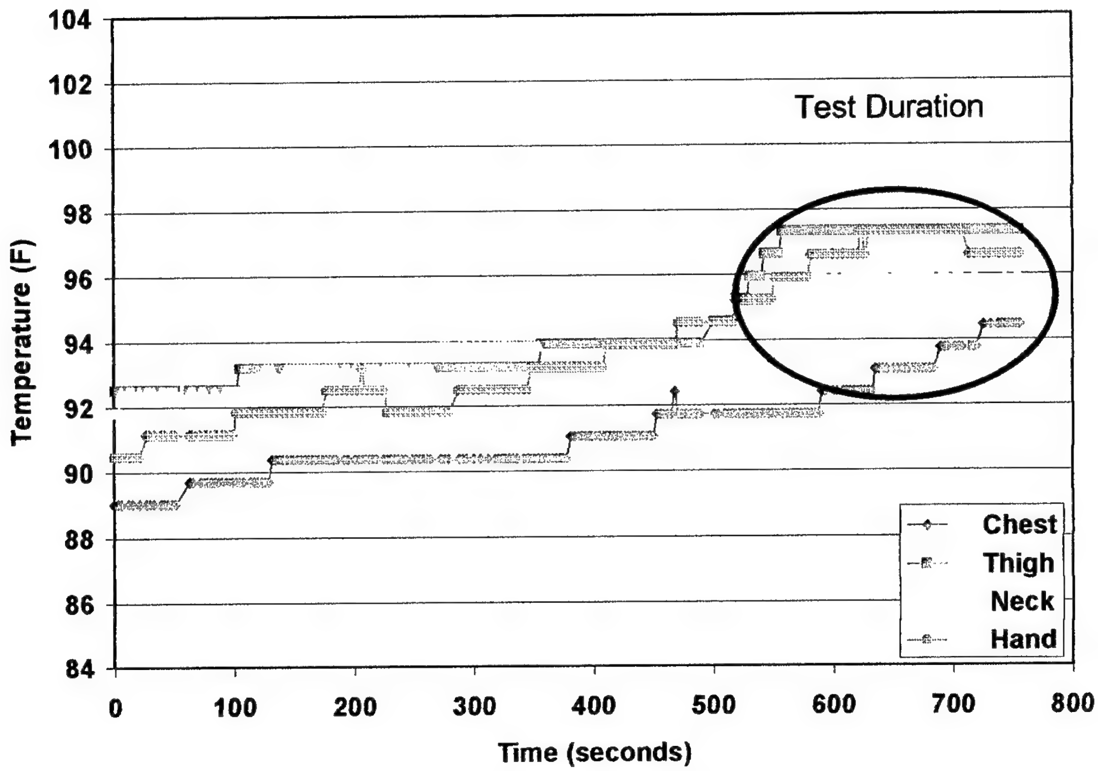

Figure 10. Skin Temperature Measurements for Test 3500-1.

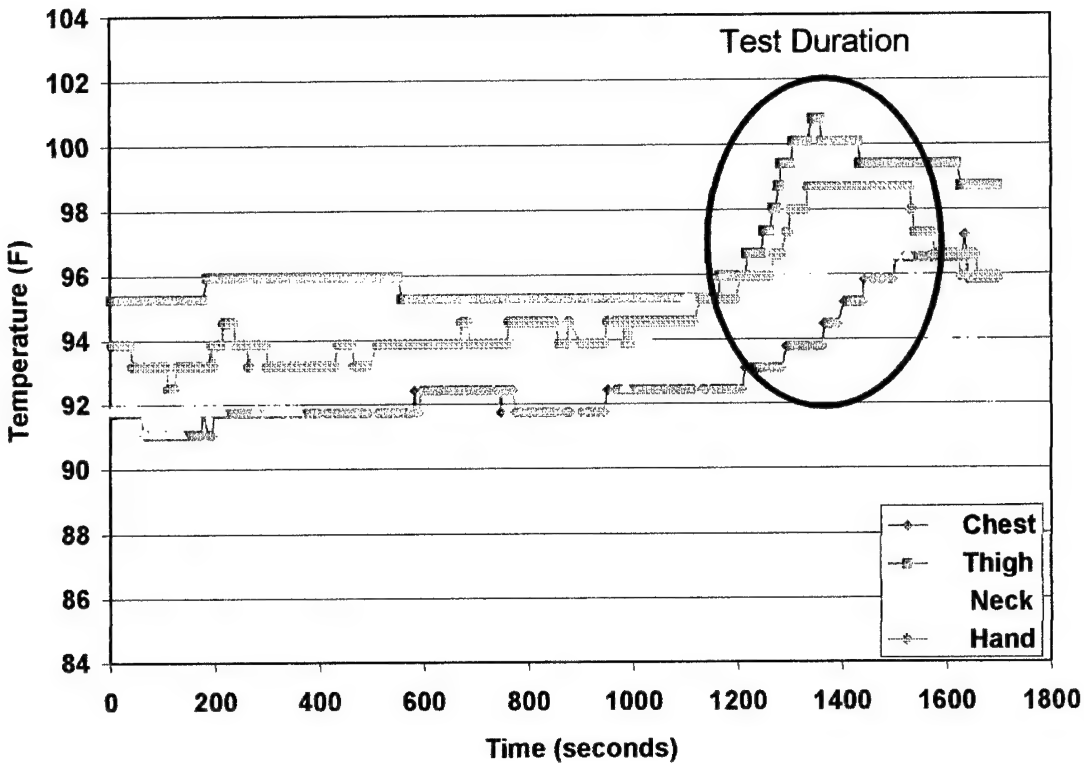

Figure 11. Skin Temperature Measurements for Test 7800-1.

C. *System Evaluation*

1. Maximum Throw Distance

Overall, both systems performed similarly (Table 8). All three tests showed a maximum throw range (with or without wind) of 64-73 feet, or well beyond the 50-foot minimum distance criteria. The second set of tests performed with each system (M2501810-2 and M2510800-2) showed results within 2-3 feet of each other. Wind velocity recorded during testing ranged from 1-2 mph with gusts up to 5 mph and accounts for the small differences observed during testing.

Table 8. Throw Distances for Both Systems at Various Elevations and Wind Conditions.

Test Number	M2501810-1	M2501810-2	M2501800-1	M2501800-2
Throw Range				
Level	54' 4"	39'	No Test-	42' 11"
Max @ 20°	73' 3"	66' 10"	Foam Meter	64' 9"
Max w/ wind	No data	No data	Not Set	71' 5"

2. Agent Application Duration

During test M2501810-1, the firefighter briefly (2-3 seconds) turned off the nozzle. During this interval, the stopwatch was stopped then restarted once the nozzle was turned back on. Both systems showed consistent application duration times in excess of five minutes and within nine seconds of each other (Table 9). Note: MARCORSYSCOM and AFRL noted the low-level aural alarm sounded at approximately four minutes into agent application duration testing. The alarm timing was consistent with the requirement for the alarm to sound when 20% water capacity remained.

Table 9. Agent Application Duration in Minutes for Both Systems.

Test Number	M2501810-1	M2501810-2	M2501800-1	M2501800-2
Duration	5:12:19	5:21:13	No data	5:15:53

3. Agent Stream Decay over Application Time

Agent stream decay was an important system parameter to monitor. System operators need to know if the throw distance changed as the agents were being depleted. Evaluation of the video from both systems showed that the agent stream remained steady in flow rate and throw distance until the water level became to low for the pump to siphon. This data showed that the firefighter could expect over 4½ minutes of consistent agent application (Table 10).

Table 10. Time Elapsed Before Agent Stream Showed Decay.

Test Number	Time (minutes)
M2501810-1	4:48:37
M2501800-1	No data-foam meter not set
M2501810-2	5:07:31
M2501800-2	4:41:29

4. Agent Discharge Flow Rate

Video of these tests showed that the agent stream changed little over the course of discharge, which indicated a consistent flow rate. An inline flow meter was not installed for this test series for real time flow rate data and the flow rate had to be calculated as an overall average by dividing the volume of water in the tank by the time to discharge the full tank. The flow rates were similar between tests/vehicles and ranged from 37.37-38.44 gpm (Table 11).

Table 11. Flow Rate Measurements in Gallons per Minute (GPM) for Both Systems.

Test Number	M2501810-1	M2501810-2	M2501800-1	M2501800-2
Flow Rate	38.44	37.37	No data	38.03

5. Foam Expansion Ratio and 25% Foam Drainage Time

Foam expansion ratio and drainage tests conducted on the foam produced from test M2501810-2 showed that the system exceeded minimum requirements as stated in NFPA 412. NFPA minimum requirements for aspirated (or compressed air) AFFF are 5:1 expansion ratio (Table 12). System M2501810 produced foam with an expansion ratio of 5.73-5.85:1 (Table 13). Similarly, the NFPA minimal requirement for 25% drainage time using test method A is 3 minutes (Table 12). System M2501810 produced foam with a 25% drainage time of 4.27-4.36 minutes (Table 13).

Table 12. NFPA Foam Quality Requirements.

		Min Solution 25% Drainage Time in Minutes	
	Min Expansion Ratio	Test Method A	Test Method B
AFFF, Aspirated	5:1	3	2.25
AFFF, Non-aspirated	3:1	1	0.75
Protein	8:1	No data	10
Fluoroprotein	6:1	No data	10

Table 13. Results from Expansion Ratio and Drainage Testing for System M2501810.

Samples	Expansion Ratio	25% Drainage
A	5.73	4.36
B	5.85	4.27

6. Foam Concentration

The refractometer allows a rough estimate of foam concentration because of the large range of the scale being used. The second method employed (measuring quantities of water and foam use) provided a more accurate method for determining the actual concentration.

By Refractometer

A Reichert Model 10440, 0-30 Hand Refractometer was used for taking readings. Refractometer readings showed a consistent 3% foam concentration (Table 14).

Table 14. Foam Concentration Based on Refractometer Tests

Test Number	Refractometer
	Before Test/After Test
2500-1	No data
2500-2	No data
2500-3	0.03/0.03
2500-4	0.03/0.03
2500-5	0.03/0.03
3500-1	0.03/0.03
7800-1	0.03/0.03

By Quantity of Agent Used

Foam concentrations calculated on the quantities of water and foam used for each test showed that the foam concentration was consistently over the desired 3%. Foam concentrations ranged from 3.5-4.24% during the six fire scenario tests evaluated (Table 15). Test 2500-3 exceeded the NFPA 412 maximum concentration allowance by 0.024. The remaining tests showed concentrations within the NFPA range of 2.8-4.0%, with the CAFS-M always metering the foam at a higher concentration rate than 3%.

Table 15. Foam concentration Based on the Use of Water and Foam.

Test Number	Agent Concentration
2500-1	No data
2500-2	0.0364
2500-3	0.0424
2500-4	0.0400
2500-5	0.0346
3500-1	0.0350
7800-1	0.0350

IV. Conclusions

A. *Fire Scenarios*

1. 2500 Sq. Ft. Fires

The CAFS-M exceeded the ARFF requirements for control (<60 seconds) and extinguishment (<120 seconds) of a 2500-ft^2 hydrocarbon pool fire. All four fires reported control time less than 60 seconds and extinguishment times less than 63 seconds.

2. 3500 Sq. Ft. Fire

The CAFS-M demonstrated improved fire control and extinguishment times of a 3500-ft^2 hydrocarbon pool fire. While maximum control and extinguishment times were not established for this test, the CAFS-M was able to fully extinguish the pool fire within the 120 second criteria established for the 2500-ft^2 pool fires. Modifications to the CAFS-M, especially the increase in agent flow rate, have drastically improved the performance of the system in both control and extinguishment times.

3. 7800 Sq. Ft. Fire

The 7800-ft^2 test was performed with winds of 4-5 mph. Due to the increase in wind velocity, the fire only involved approximately 2/3, or 5200-ft^2, of the 7800-ft^2 full pit area. While maximum control and extinguishment times were not established for this test, the CAFS-M was able to fully extinguish the pool fire within the 120 second criteria established for the 2500-ft^2 pool fires. The CAFS-M successfully controlled and extinguished a 5200-ft^2 hydrocarbon pool fire without depleting the system capacity. Based on the time to full extinguishment, the CAFS-M used approximately 25% of its available agent while extinguishing more than two times the required pool fire area.

B. *Human Factors*

Radiant Heat Effects on Firefighters

Skin temperature measurements were consistent at 102°F or less. The throw distance and discharge rate of the CAFS-M allowed the firefighter to maintain a safe standoff distance from the fire, which reduced radiant heat exposure and prevented any subsequent skin burns.

C. *System Evaluation*

1. Maximum Throw Distance

Both systems exceeded minimum requirements of a 50-foot throw distance in straight stream mode by 14-23 feet. The CAF-M has sufficient throw distance to

provide adequate standoff distance for the firefighter, minimizing radiant heat exposure.

2. Agent Application Duration

The CAFS-M has sufficient agent application to completely extinguish a fire three times the minimal requirement using only 25% of its capability.

3. Foam Stream Decay over Application Time

The CAFS-M provided consistent agent throw during the entire system capacity. The agent stream did not decrease in throw range until the water level in the tank became to low for the pump to siphon.

4. Agent Discharge Flow Rate

The CAFS-M exceeded the manufacturers specified nominal flow rate of 30 to 35 gpm in full wet setting. The flow rate calculated during the three tests showed that the flow rate average 37.37 to 38.44. NFPA 414 for ARFF vehicle flow rate tolerances states that the flow rate must be +10 percent/-0 percent (35.0-38.5 gpm) of the manufacturers specifications. Based on a 35 gpm manufacturer specification, the CAFS-M flow rate was within NFPA standards.

5. Foam Expansion Ratio and 25% Drainage Time

The CAFS-M (on the wet setting) exceeded minimum NFPA 412 requirements for foam expansion ratio and 25% drainage times.

6. Foam Concentration

Both methods employed for determining foam concentration showed that the CAFS-M maintained a minimum of 3% foam concentration.

V. References

1. Test Plan: Compressed Air Foam System-Mobile. Marine Corps Systems Command. July 2001.
2. Test Plan: Marine CAFS-M System Testing. Air Force Research Laboratory. August 2001.
3. Ferraro, A. Evaluation of the U.S. Marine Corps Compressed Air Foam System Mobile. Naval Air Warfare Center Aircraft Division. NAWCADPAX/TR-2001/18. February 2001.
4. Scalds: A Burning Issue. A Campaign Kit for Burn Awareness Week 2000. American Burn Association. 2000.
5. NFPA 414: Standard for Aircraft Rescue and Fire-Fighting Vehicles. National Fire Protection Agency. 1995 Edition.
6. NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment. National Fire Protection Agency. 1998 Edition.

Appendix

All firefighting gear used during this evaluation meets NFPA 1976 Standards, 200 Edition.

Firefighting Equipment

Proximity Coat

Morning Pride, Model # BPR 7602TS

Proximity Trouser

Morning Pride, Model # BPR7602PS

Proximity Gloves

Morning Pride, Model # BPR-RWA

Proximity Helmet

Morning Pride, Model # AXR747

Self Contained Breathing Apparatus

Interspiro, Model # 9030

Data Acquisition System

Computer: Dell Inspiron 3800, Pentium III 600
Data Acquisition: Mini Mitter VitalSense, version 2.1 with an approximate sampling rate of 1 sample per 3 seconds or 20 samples per minute.

General Requirements for Expansion and Drainage Methods, Method A

- The foam sample shall be collected in a standard 1000-ml capacity graduated cylinder. The cylinder shall be cut off at the 1000-ml mark to ensure a fixed volume of foam as a sample. The cylinder shall be marked in 10-ml graduations below the 100-ml mark. The container will be weighed dry to the nearest gram.
- The foam nozzle will be deflected off to the side of the foam collector until normal operating pressure and flow rate are achieved.
- The foam sample container will be completely filled with foam, the discharge nozzle will be shut off and the timing of the 25% drainage will begin.
- The foam container will be removed from the base of the foam collector and excess foam will be removed (from top and sides).
- The container will be placed on the balance and total weight of foam and container will be determined to the nearest gram. The weight of the foam will be determined from subtracting the weight of the empty container from the weight of the full container. The weight of the foam sample in grams will be divided by four to obtain the equivalent 25% drainage volume in milliliters.
- The foam sample will be placed on a level surface and the level of accumulation solution in the bottom of the cylinder will be noted and recorded every 30 seconds. The drainage will be recorded until 25% volume has been exceeded. The 25% drainage time will be interpolated from the data. Assume that 1 g of foam solution occupies approximately 1 ml.
- Expansion ration is as follows: Expansion = 1000 ml / (full weight) - (empty weight)
- Drainage Volume, 25% = volume of solution / 4

Foam Solution Concentration Determination, Method B

Using water and foam concentrate from the tanks of the vehicles to be tested, sample concentrations shall be determined as follows:

- Obtain a foam concentration sample in a clean container and label "foam concentrate".
- Obtain a water sample from the truck water tank or pump water discharge in a second clean container and label "water".
- Allow foam concentration to discharge from a hoseline or turret for at least 30 seconds. Obtain a foam solution sample from the discharge device in a third clean container and label "foam solution". The portions of drained solution obtained during the previously described drainage test can be used for the "foam solution" sample.
- Take a refractive index reading of the water sample, R_W, and then clean the instrument.
- Take a refractive index reading of the foam concentrate, R_C, and then clean the instrument.
- Take a refractive index reading of the foam solution, R_S.
- % Foam Concentration $= R_S - R_W / R_C - R_W \text{ X } 100$

List of Acronyms

Air Combat Element (ACE)

Air Force Research Laboratory (AFRL)

Compressed Air Foam (CAFS)

Combat Service Support Element (CSSE)

Commercial Utility Cargo Vehicle (CUCV)

Compressed Air Foam Mobile System (CAFS-M)

Gallons Per Minute (GPM)

High Mobility Multipurpose Wheeled Vehicle (HMMWV)

Key Performance Parameters (KPP)

Marine Air Ground Task Force (MAGTF)

Marine Corps System Command (MARCORSYSCOM)

National Fire Protection Agency (NFPA)

Operational Requirements Document (ORD)

Twin Agent Unit (TAU)